ZooKeys 660: 1–16 (2017)
doi: 10.3897/zookeys.660.11228
http://zookeys.pensoft.net

RESEARCH ARTICLE

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Notaulax yamasui sp. n. (Annelida, Sabellidae) from Okinawa and Ogasawara, Japan, with notes on its ecology

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Academic editor: *C. Glasby* | Received 17 November 2016 | Accepted 1 February 2017 | Published 7 March 2017

http://zoobank.org/48C4C2C9-2EE6-40F9-B840-CFC6CB072551

Citation: Nishi E, Gil J, Tanaka K, Kupriyanova EK (2017) *Notaulax yamasui* sp. n. (Annelida, Sabellidae)from Okinawa and Ogasawara, Japan, with notes on its ecology . ZooKeys 660: 1–16. https://doi.org/10.3897/zookeys.660.11228

Abstract

The polychaete *Notaulax yamasui* **sp. n.** (Sabellidae) is described from Okinawa and Ogasawara, south Japan, where it was found living embedded in a dead skeleton of the coral *Porites* sp. The new species is characterized by the presence of a pigmented sub-distal swelling on the tips of the crown radioles, a unique feature among species of the genus. Besides, its collar chaetae have an L-shape orientation, and the dorsal basal flanges of the branchial lobes are long and have a dorsal joint.

Keywords

Boring species, coral reef, new species description, Polychaeta, taxonomy, worms

Introduction

A revision of the Japanese sabellid polychaetes belonging to the genera *Megalomma* Johansson, 1925, *Notaulax* Tauber, 1879, *Parasabella* Bush, 1905 and *Sabella* Linnaeus, 1767, is in progress. In the course of this revision, several Japanese collections are being revised for specimens belonging to these genera. As a result, two specimens belonging to the same species showed radioles with sub-distal swellings, like those found in *Sabella discifera* Grube, 1874 and in *Bispira brunnea* (Treadwell, 1917), as reported by Tovar-Hernández

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and Pineda-Vera (2008). These swellings can be pigmented, in which case they superficially resemble the compound eyes of *Megalomma* and *Stylomma* Knight-Jones, 1997. Other main features of the specimens include the long flanged radiolar lobes (similar to those in *Notaulax*, *Stylomma*, and *Anamobaea* Krøyer, 1856), and simple radiolar eyes (like those in *Notaulax*, *Anamobaea*, and *Hypsicomus* Grube, 1870). All these genera were revised or described by Rullier and Amoureux (1970), Perkins (1984), Knight-Jones (1997), Knight-Jones and Perkins (1998), Fitzhugh (2002) and Capa (2007). Further information on these genera can also be found in Fitzhugh (1989, 2003) and Capa et al. (2014).

The specimens collected at Okinawa and Ogasawara (south-western Japan) were studied using both light and scanning electron microscopy (SEM) for their external morphology, and through histological cross sections at different levels of the radioles for the internal anatomy of the radioles and their sub-distal swellings. As a result, the specimens were determined to belong to an unknown species of *Notaulax*, which is described below as a new taxon.

Material and methods

The specimens were collected together with the surrounding coral at shallow water by hand, using chisels to break pieces of the coral, and fixed in the laboratory with a 10% seawater-buffered formalin solution. Some parapodia were removed from the body and prepared for microscopy observations. For light microscopy observations the parapodia were placed on a microscope slide, covered with a cover slip, and gentle pressure was applied in order to observe the chaetae and uncini. Histological sections were made from radioles embedded in paraffin, cut on a microtome, and stained with Sudan Black B. For SEM observations, the parapodia were run through a series of increasing concentrations of ethanol (80, 90, 95, 99 and 100%), air-dried, coated with palladium and platinum, and viewed in a Hitachi S-800 SEM. The holotype and paratype were deposited in the Coastal Branch of Natural History Museum and Institute, Chiba at Katsuura, Chiba, Japan (catalogue code, CMNH-ZW). The terminology for the anatomical structures of *Notaulax* follows Fitzhugh (1989, 2002).

Systematics

Genus *Notaulax* Tauber, 1879

***Notaulax yamasui* sp. n.**
http://zoobank.org/841FE0ED-E2E5-44E7-AFB4-8FDB399251D9
Figs 1–3, 4A–B, 5A–E

Material examined. Holotype: CMNH-ZW00217, complete specimen with fragment of tube, extracted from living coral mass of *Porites* sp., collected in the subtidal zone

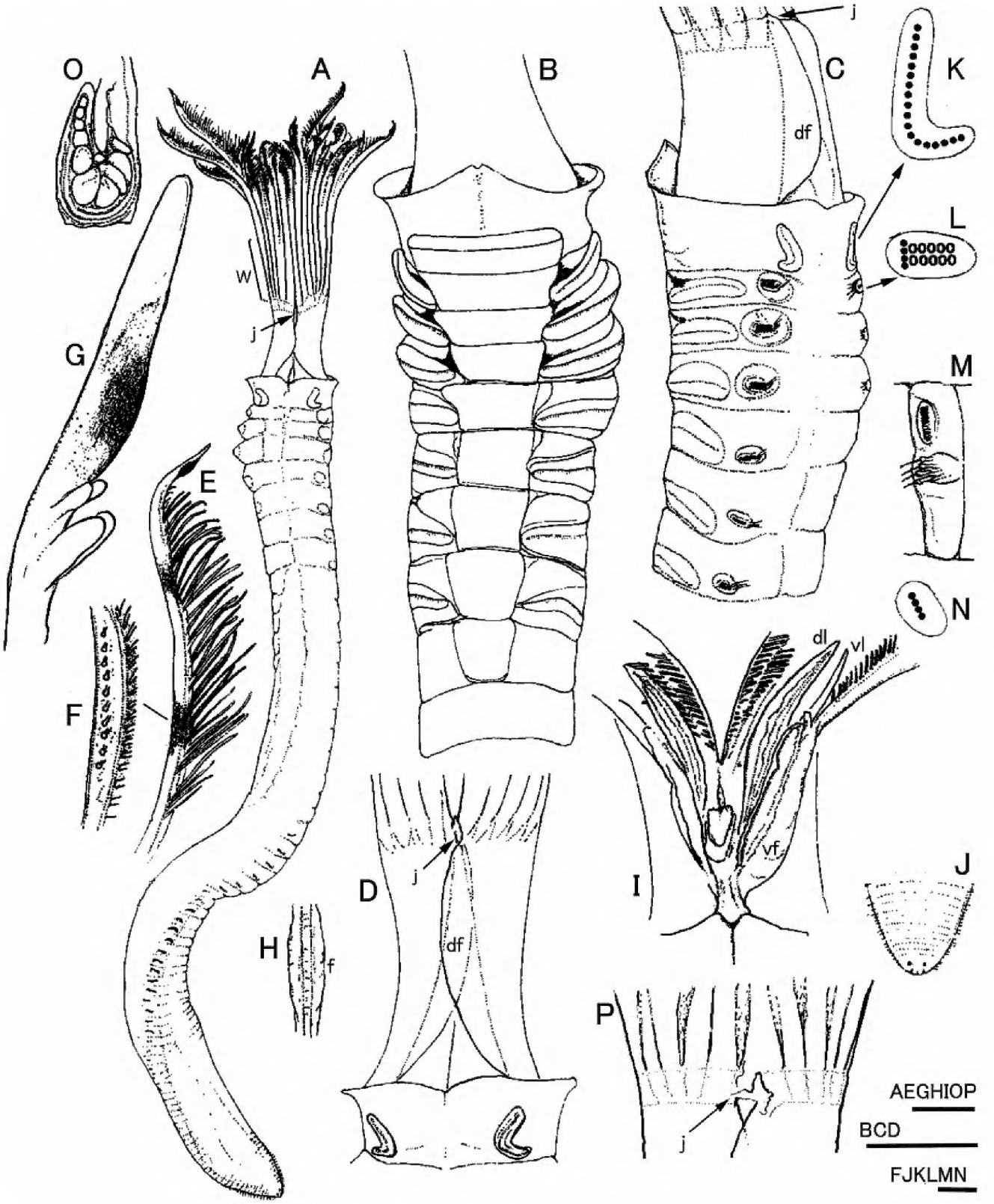

Figure 1. *Notaulax yamasui* sp. n.: **A** holotype, dorsal view **B** ventral view of thorax **C** latero-dorsal view of left side of thorax **D** dorsal view of first chaetiger and radiolar base **E** distal side view of radiole **F** middle region of radiole showing a row of simple radiolar eyes **G** lateral close up view of tip of radiole, with pigmented sub-distal swelling **H** basal part of radiole showing paired longitudinal flanges (f) **I** schematic ventral view of interior of crown showing dorsal lip (dl), ventral lip (vl), ventral flange of radiolar base margin (vf) **J** posterior abdomen and pygidium, showing eye-spots **K** schematic arrangement of collar chaetae, right side **L** schematic arrangement of thoracic chaetae from second chaetiger, black spots representing superior chaetae, white circles representing inferior chaetae **M** anterior abdominal segment, left side view **N** schematic arrangement of neuropodial abdominal chaetae **O** cross-section of radiole, middle region **P** base of radioles and inter-radiolar membrane. Abbreviations: df, dorsal basal flange; dl, dorsal lip; f, longitudinal flange; j, junction of dorsal basal flange; vf, ventral flange; vl, ventral lip; w, inter-radiolar membrane. Scale bars 1 mm (**A, B, C**), 0.5 mm (**D, J**), 0.25 mm (**E, F, H, K, P**), 0.1 mm (**G, I, L, M, N, O**).

(0–2 m) of a shallow coral reef area at Maeda-Misaki Cape, 26°26.716'N, 127°46.329'E, Okinawa Island, Ryukyu Archipelago, south-western Japan, Pacific Ocean, 13 February 1996, by hand, coll. by E. Nishi. Paratype: CMNH-ZW00220, incomplete specimen lacking posterior abdomen and tube, collected on a dead *Porites* sp. coral colony, at Kominato, Chichi-jima Island, Ogasawara Archipelago, south-east Japan, Pacific Ocean, 16 July 1999, coll. by Prec. Institute Co Ltd.

Comparative material. *Megalomma* sp., CMNH-ZW uncatalogued, Yoshio, Katsuura, Boso Peninsula, Japan, subtidal, coll. by E. Nishi.

Diagnosis. Pigmented sub-distal swelling on tips of crown radioles; collar chaetal row in L-shape orientation; dorsal basal flanges of radiolar lobes long and with a dorsal joint.

Description. *Tube* dark brown, thin and membranous. Body and radiolar crown pale in preserved specimens, except for light brown collar and for two (upper and lower) brown bands on distal free region of radioles (Fig. 1A, E).

Body of holotype 40 mm long (excluding crown) for 130 chaetigers (including thorax and abdomen); thorax 4 mm long and 2.0-2.5 mm wide, excluding chaetae; radiolar crown 6 mm long, radiolar lobes 1 mm long. Paratype similar in size, body 6 mm long (posterior portion of abdomen missing) for 32 chaetigers, thorax 3 mm long and 1.5 mm wide, excluding chaetae; radiolar crown 7 mm long, radiolar lobes 1.5 mm long.

Crown with 16 pairs of radioles, joined by inter-radiolar membrane (Fig. 1C, D, P), inter-radiolar membrane about 1/2 length of radiole length (Fig. 1A); radiolar lobes with narrow dorsal flanges (Fig. 1 A, C), flanges closed at lower level of inter-radiolar membrane by dorsal joint (Fig. 1P), and free proximally (Fig. 1C, D); ventral margins of radiolar lobes also flanged, ventral flanges free (Fig. 1I); radioles with 4 or more skeletal cells in cross-section (Figs 1O, 5B, C, D, E), with paired longitudinal flanges on outer surface, more prominent at basal region near inter-radiolar membrane (Figs 1H, 4B, 5C), turning distally into flattened long tongue-shaped tips (Figs 1A, E, G, 4A, 5A); each radiole with one pigmented sub-distal swelling on inner side (not pigmented in paratype, showing same color to rest of body) (Figs 1A, E, G, 4A, 5A) and 8-12 pale brown simple radiolar eyes in single row on each side, at lateral margin of central region of radioles (within lower brown band) (Fig. 1E, F). Dorsal lips long, tapered to slender, with supporting mid-rib, joined to adjacent radiole (= radiolar appendage), but not to basal pinnule (Fig. 1I). Ventral lips tapered and small, merging proximally into parallel lamellae (Fig. 1I); ventral sacs absent.

Thorax with eight chaetigers; posterior peristomial ring collar entire, without dorsal or ventral slits, well separated from peristomium, with straight brown line above ventral glandular shield (Fig. 1B), mid-dorsal margin slightly embayed, lateral margin transverse to body axis and extending well above junction of radiolar crown with thorax, ventral margin raised in middle and incised ventrally with small notch on midline (Fig. 1B, C, D). First ventral glandular shield rectangular, divided transversally, with nearly straight anterior margin, slightly wider than shield of chaetiger 2 and about 2/3 longer (Fig. 1B). Other thoracic ventral glandular shields sub-trapezoidal (broader anteriorly), margins postero-laterally indented by tori. Abdomen with 122 (holotype) and 24 (paratype, posterior region missing) chaetigers. Pygidial eyespots present (Fig. 1A, J).

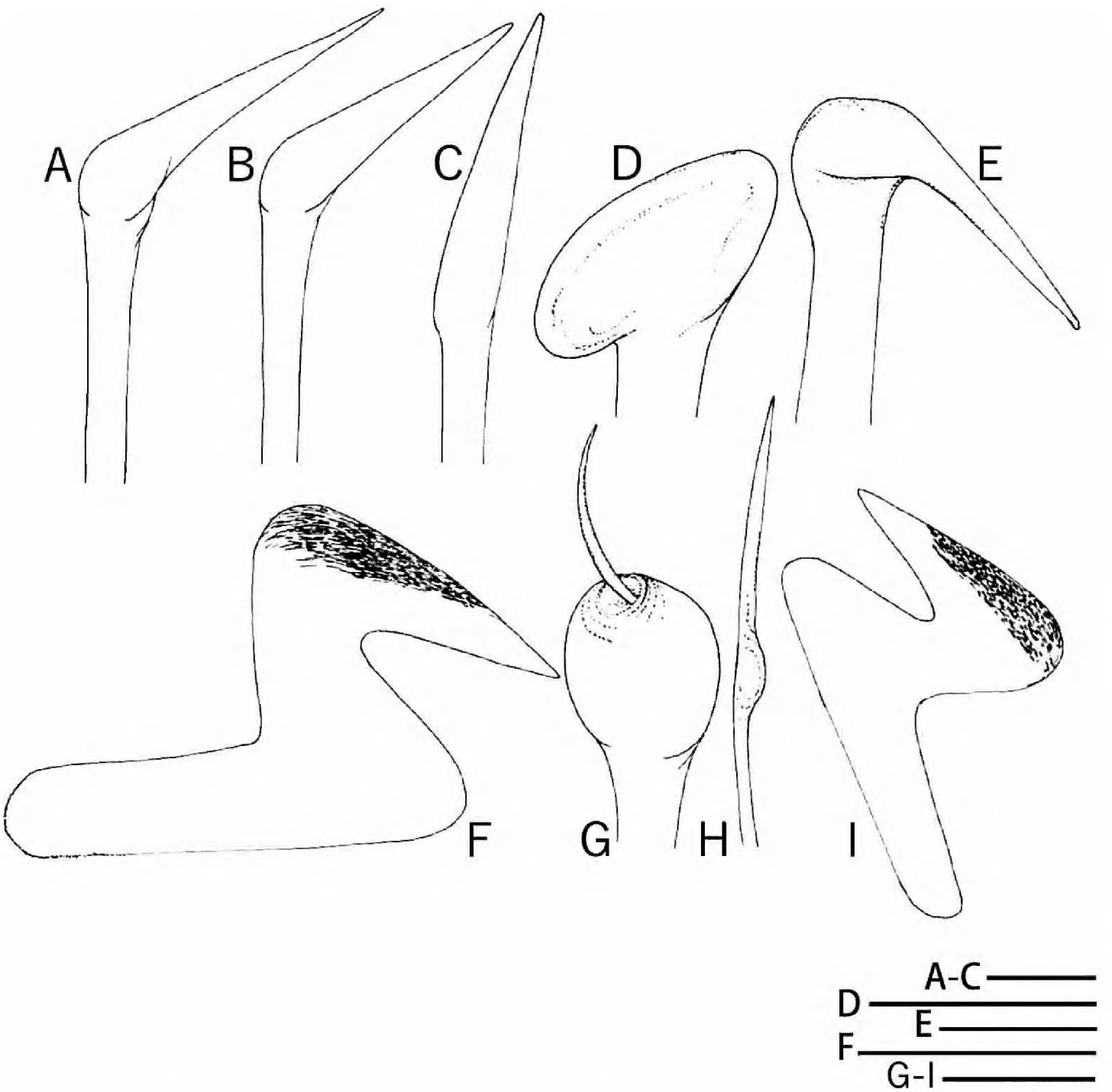

Figure 2. *Notaulax yamasui* sp. n. Chaetae of thorax (**A–E**) and abdomen (**G, H**) drawn from SEM micrographs, and uncini (**F, I**), drawn under a dissecting light microscope. **A–B** collar chaetae **C** superior thoracic chaeta **D** inferior thoracic chaeta **E** companion chaeta, dorsal view **F** thoracic uncini **G** inferior abdominal chaeta, anterior abdominal chaetiger **H** inferior abdominal chaeta, posterior abdominal chaetiger **I** abdominal uncini. Scale bars 20 μm (**A–C**), 50μm (**D**), and 30μm (**E–I**).

Collar chaetae spine-like, each with knee wider than shaft (Figs 2A, B, 3A), in longitudinal rows, curved outwards posteriorly (Fig. 1C, D, K). Superior chaetae of thoracic notopodial fascicles spine-like, similar to chaetae in chaetiger 1 (Figs 2C, 3B, C) and in short row (Fig. 1L), dorsal to paleate inferior thoracic notochaetae with hoods distally rounded (Figs 2D, 3B, C), arranged in two transverse rows (Fig. 1L). Thoracic neuropodial fascicles with avicular uncini, with several minute teeth above main fang, prominent breast and handle longer than distance between breast and main fang (Figs 2F, 3D). Companion neurochaetae in row parallel and anterior to uncini, with broad, thin teardrop-shaped blades at right angle to shafts, pointing anteriorly (Figs 2E, 3D).

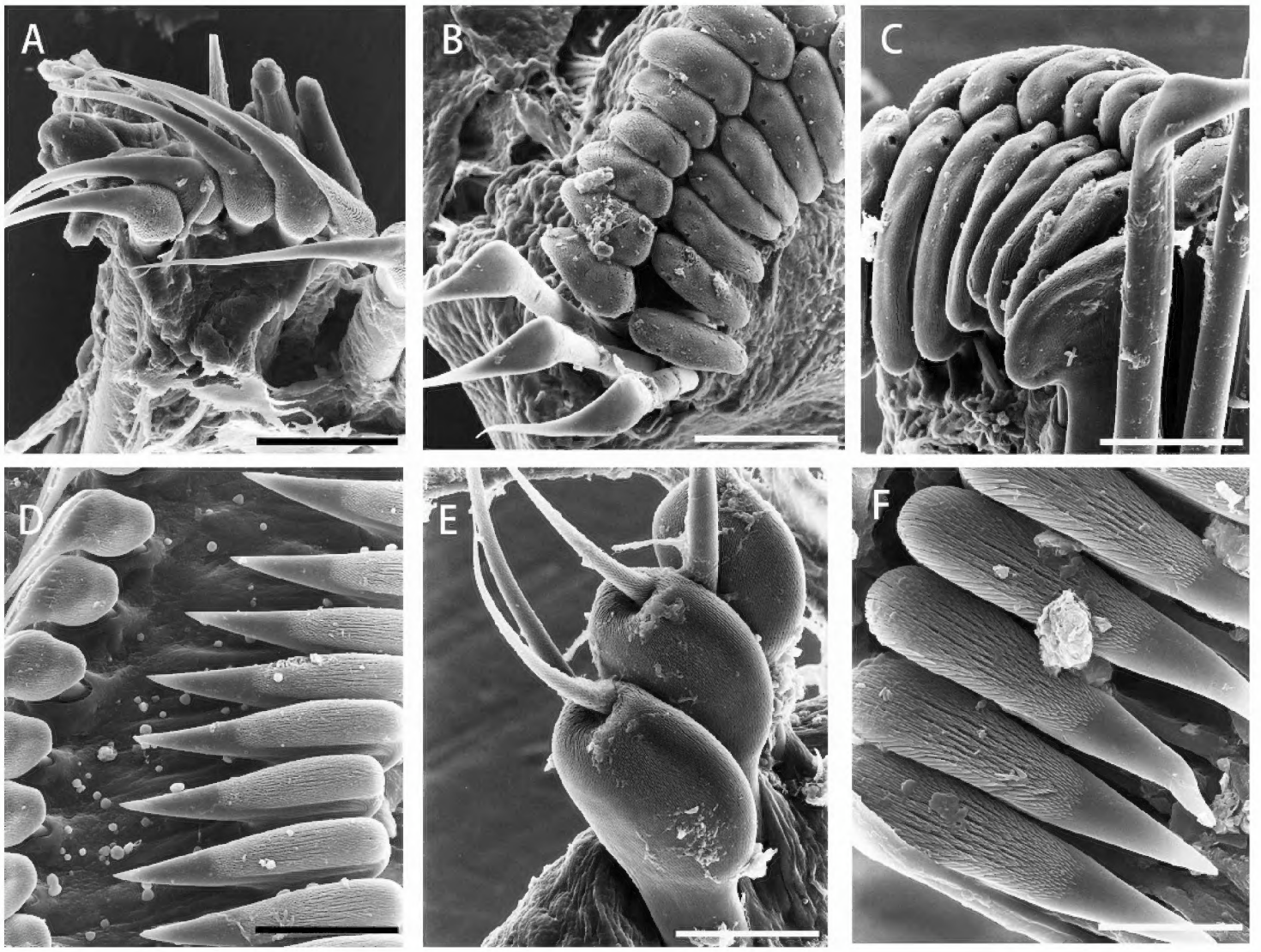

Figure 3. *Notaulax yamasui* sp. n. SEM micrographs of chaetae and uncini. **A** collar chaetae **B** 3rd left notopodial thoracic fascicle **C** detail of B, showing superior chaetae **D** uncini and companion chaetae, 3rd thoracic neuropodial torus **E** inferior abdominal spatulate chaetae showing distal mucros from 7th fascicle of abdomen, lateral view **F** abdominal uncini. Scale bars 30μm (**A**), 60μm (**B**), 40μm (**C**), 30μm (**D, E**), 12μm (**F**).

Abdominal neuropodia with neuropodial fascicles of paleate chaetae in short transverse rows (Fig. 1M, N); paleate neurochaetae with distal mucros shorter than hooded area in anterior abdominal segments (Figs 2G, 3E), mucros becoming longer than hooded area in posterior abdominal segments. Paleate neurochaetae numbering 4 per fascicle on most anterior abdominal segments (1st to 7th), 3 on median segments (8th to 20th), and one or two on posterior chaetigers. Superior neuropodial abdominal chaetae slender and straight, with or without sub-distal bulge (Fig. 2H), one per fascicle on anterior abdominal chaetigers (1st to 20th) and two to three in posterior ones. Abdominal notopodial avicular uncini similar to thoracic uncini (Figs 2I, 3F).

Habitat. *Notaulax yamasui* sp. n. is known to live in the subtidal zone, embedded in dead coral masses of *Porites* sp.

Etymology. The new species is named after Dr. Terufumi Yamasu, Emeritus Professor of the University of the Ryukyus, Japan, for his great contribution to the development of the Okinawan marine biology.

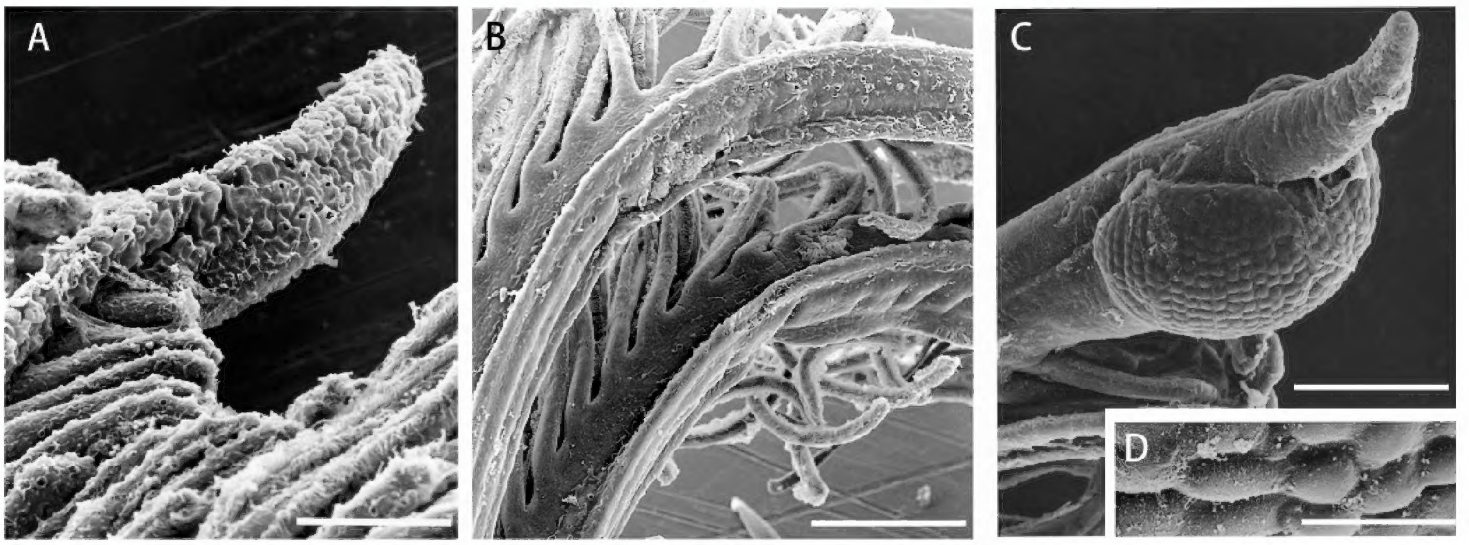

Figure 4. *Notaulax yamasui* sp. n. (**A, B**) and *Megalomma* sp. (**C, D**), SEM micrographs of anterior and middle parts of radiole and distal tip with a distal swelling in *N. yamasui* sp. n. and with a compound eye in *Megalomma* sp. **A** close-up view of a sub-distal radiolar swelling **B** middle part of radiole showing pinnules and dorsal flange **C** compound eye on radiole **D** close-up view of surface of compound eye. Scale bars 75 μm (**A**), 200 μm (**B**), 300 μm (**C**), and 30 μm (**D**).

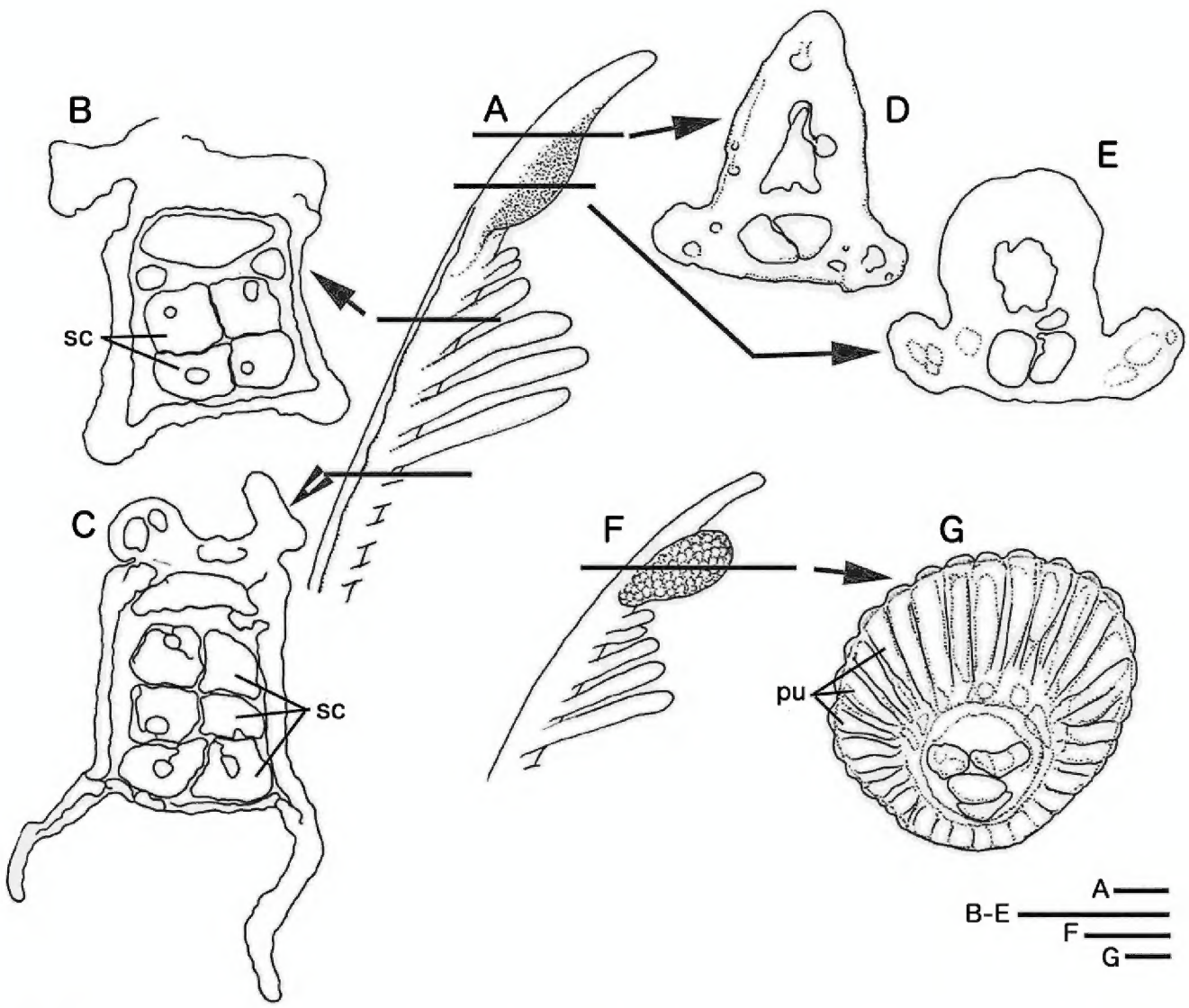

Figure 5. *Notaulax yamasui* sp. n. (**A–E**) and *Megalomma* sp. (**F, G**), internal structure of radiole. *Notaulax yamasui* sp. n. **A** radiole tip, lateral view **B, C** internal structure of proximal region of radiole **D, E**, internal structure of sub-distal swelling. *Megalomma* sp. **F, G** internal structure of compound eye **F** radiole with compound eye, lateral view **G** internal structure of compound eye, with many individual photoreceptor units (pu) **B–E** and **G** are drawn from sliced sections of eyes and radioles. Abbreviations: sc, skeletal cells; pu, photoreceptor unit. Scale bars 100μm (**A**), 200μm (**B–E**), 300μm (**F**), 20μm (**G**).

Discussion

Systematics

Under the stereo-microscope the radiolar sub-distal swellings of *Notaulax yamasui* sp. n., pigmented in the holotype, superficially resemble the typical radiolar compound eyes of the genera *Megalomma* and *Stylomma*, while other characters are typical of other sabellid genera lacking such eyes: the linear collar chaetae fascicles of *Notaulax*, *Panousea* Rullier and Amoureux, 1970, or *Panoumethus* Fitzhugh, 2002; the loosely aligned simple radiolar eyes of *Hypsicomus*, *Notaulax*, and *Anamobaea*; the long radiolar lobes of *Stylomma*, *Notaulax*, and *Anamobaea*. From these, *Panousea* and *Panoumethus* were ruled out from the beginning due to the presence of thoracic acicular uncini.

The fan-worm eyes and other photoreceptors are summarized in Bok and Nilsson (2016) and Bok et al. (2016). The compound eyes of *Stylomma* are stalked, which occurs neither in *Megalomma,* nor in the swellings of *N. yamasui* sp. n. The radiolar sub-distal swellings of the specimens of *N. yamasui* sp. n. were compared with the compound eyes of an unidentified *Megalomma* specimen collected at Katsuura, Chiba (Honshu, Japan). Scanning electron micrographs of *Megalomma* sp. eyes showed a surface structure analogous to the insect compound eyes, with many individual lenses arranged in a geometrical array (Fig. 4C, D). This does not occur in the sub-distal radiolar swellings of *N. yamasui* sp. n., where the surface of the swellings does not show any kind of special array (Fig. 4A). Moreover, while the former eyes have clearly defined edges, the latter have diffused edges around the swelling.

The internal morphology of both structures in *Megalomma* sp. and *N. yamasui* sp. n. compared through histological cross-sections showed ultrastructural differences: *Megalomma* sp. presents lenticular photoreceptor units (Fig. 5G), while the swellings of *N. yamasui* sp. n. are structurally similar to other regions of the radioles (Fig. 5B–E). These differences show that the new species lacks the compound eyes typical of *Megalomma* or *Stylomma*.

The remaining three genera (*Notaulax*, *Anamobaea*, and *Hypsicomus*) belong to a well-defined group inside the Sabellidae (Fitzhugh 1989: Clade IV in fig. 28; Nogueira et al. 2010: clade in figs 18–20, 22). These three genera share a number of features, including the presence of scattered simple radiolar eyes along the lateral margins of the radioles (Fig. 1E, F). However, *Hypsicomus* and *Anamobaea* can be easily separated from *Notaulax* and the new species by having the collar chaetae arranged in a bundle, instead of a long row. Besides, the spine-like shape of the superior thoracic notochaetae of the new species is typical of *Notaulax*, while in both *Hypsicomus* and *Anamobaea* thoracic notochaetae are elongated and narrowly hooded.

Finally, other characters typical for the genus *Notaulax* and also present in the new species, such as long flanged radiolar lobes, gave further support to its identification as a member of the genus. The genera *Hypsicomus* and *Notaulax* were partially revised by Perkins (1984) who, after examining the type species of *Hypsicomus*, the Adriatic *H. stichophthalmos* (Grube, 1863), redefined the genus and transferred to *Notaulax* all

but the type species previously included in *Hypsicomus*. This means that the literature records of coral-boring *Hypsicomus phaeotaenia sensu lato* or *Hypsicomus* ssp. would be referable to *Notaulax* species (see below).

Among the members of the genus *Notaulax* (see Perkins 1984, Capa and Murray 2015), *N. yamasui* sp. n. is unique in having radiolar sub-distal swellings and L-shaped distributed collar chaetae. Another remarkable character of *Notaulax yamasui* sp. n. is the structure of the dorsal basal flange, which is rounded and long (Fig. 1A, D), with bases closed dorsally by a dorsal joint (Fig. 1P). A similar structure was reported in *Stylomma palmatum* (Quatrefages, 1866) by Capa (2008). In Japanese waters, the only recorded *Notaulax* species is *N. lyra* (Moore and Bush, 1904). *Notaulax yamasui* sp. n. is differentiated from *N. lyra* by the presence of radiolar subdistal swellings, a much longer inter-radiolar membrane which is about half the length of the radioles (Fig. 1A), and the color pattern of radioles (two or three brown bands in the former species, and reddish brown eyes pots occupying the basal three-tenth of radiole in the latter species) (Imajima and Hartman 1964).

The entire posterior peristomial ring collar is also an uncommon feature among *Notaulax* species, being described only in two other species: *Notaulax pyrrhogaster* (Grube, 1878) from Philippine Islands, and *N. alticollis* (Grube, 1868) from the Red Sea. Like in these two species, *N. yamasui* sp. n. also shows the ventral margin of the collar more or less extended forward, forming a triangular lobe. However, neither of those two species has radiolar distal swellings, nor the collar chaetae in an L-shaped arrangement. Besides, *N. pyrrhogaster* does not show simple radiolar eyes (likely not faded by alcohol, as according to Wiktor (1980), the syntype has been preserved in formalin), and *N. alticollis* has the group of radiolar eyes positioned along two rows with less than 15 eyes in each, corresponding to about 7 pinnules in length. *Notaulax yamasui* sp. n. has the radiolar eyes in a group corresponding to about 11-12 pinnules in length, with 8–12 eyes in a single row. Capa and Murray (2015) recorded *Notaulax* sp., having radiolar eyes (noted as radiolar ocelli) arranged in a single row or in teardrop-shaped groups. Other types of radiolar eyes and further details about their structure can be found in Bok et al. (2016).

Ecology of *Notaulax*

The two types of *Notaulax yamasui* sp. n. were found living embedded in dead masses of coral *Porites* sp. Boring by worms in coral reefs is a common and very well-known phenomenon described as early as in 1902 by Gardiner (1902), and recently revised by Hutchings (2008). With the prevalent predation pressures at shallow coral reefs being high, the advantage of burrowing for protection into hard surfaces such as corals seems obvious, with positions submitted to currents and vertical surfaces being particularly favored by filter feeders to maximize feeding benefits and avoid sedimentation (Elias 1986, Hutchings 1986). Normally worms only bore into dead corals, or in the dead edges of living corals, avoiding contact with the soft parts. The recruitment by the worms is believed to be entirely *via* larvae or juveniles settling on the surface; as coral

polyps are carnivores, the successful recruitment and subsequent boring is restricted mainly to the coral areas where polyps are damaged or very scarce (Hutchings and Murray 1982, Hutchings 2008).

Boring by worms plays an important role in the bio-erosion of coral reefs, but much less so than grazing by echinoids and fish, with boring polychaete species belonging to several families (the most important being Eunicidae, Lumbrineridae, Dorvilleidae, Oenonidae, Spionidae, Cirratulidae, and Sabellidae) and also Sipuncula (Warme 1975, Hutchings 1986, Hutchings and Peyrot-Clausade 2002, Hutchings 2008). Boring mechanisms in polychaetes can include mechanical (Eunicida) or chemical methods (Spionidae, Sabellidae, and probably Cirratulidae) (Hutchings 2008), and normally tubes or holes made by boring organisms can be recognized by their nearly constant diameter, as they are bored continuously to accommodate the growth of the host corals (Nishi and Nishihira 1999).

Many (if not all) Sabellidae *sensu* Kupriyanova and Rouse, 2008 secrete mucus tubes by ventral sacs, general body walls, ventral gland shields, and parapodial glands, and at least in five genera (*Sabella*, *Myxicola* Koch in Renier, 1847, *Pseudopotamilla* Bush, 1905, *Perkinsiana* Knight-Jones, 1983, and *Sabellastarte* Krøyer, 1856) the tubes are made of acid mucopolysaccharide-protein complexes (Chungtai and Knight-Jones 1988, Hutchings 2008). Hartman (1954) already suggested that the penetrating effect of *Notaulax* sp. (as *Hypsicomus phaeotaenia*) could be a result of a chemical action on the coral surface (see below).

Similarly, larvae of *Notaulax* species settle on dead corals, probably benefiting from the rugose surface for protection, while burrowing holes into the dead coral mass. A transverse section of a *Notaulax* sp. burrow in a *Porites* sp. coral is represented in Nishi and Nishihira (1999).

Many sabellids are known to live in hard carbonate substrates and some of them have been described as having their tubes embedded into substrates such as rocks (*Sabellastarte magnifica* (Shaw, 1800); *Pseudopotamilla reniformis* (Bruguière, 1789); *Parasabella saxicola* (Grube, 1861), as *Demonax brachychona* (Claparède, 1870); *Potamethus mucronatus* (Moore, 1923)), concretions of coralline algae (*Demonax langerhansi* Knight-Jones, 1983), shells or limestone (*Perkinsiana rubra* (Langerhans, 1880)), abalone shells (*Terebrasabella heterouncinata* Fitzhugh and Rouse, 1999) or shells of freshwater mollusks (genus *Caobangia*) (Jones 1974, Chughtai and Knight-Jones 1988, Fitzhugh and Rouse 1999, Kuris and Culver 1999, Simon et al. 2005, Moreno et al. 2006).

At least seven species of *Notaulax* live embedded in dead corals (see below), and the same is true for one undescribed *Megalomma* species (Chughtai and Knight-Jones 1988), one undescribed species of Fabriciidae (Hutchings and Peyrot-Clausade 2002), *Potamilla ehlersi* Gravier, 1906, *Megalomma claparedii* (Gravier, 1906) (as *Branchiomma*), *M. circumspectum*, *Branchiomma* cf. *bairdi*, *Megalomma mushaense* (Gravier, 1906) (as *Branchiomma mushaensis*), *Megalomma miyukiae* Nishi, 1998, *Perkinsiana fonticula* (Hoagland, 1919) (as *Parasabella*), *Amphicorina schlenzae* Nogueira and Amaral, 2000, *A. bichaeta* Capa and López, 2004, *A. perkinsi* Capa and López, 2004, *Amphiglena jimenezi* Capa and López, 2004, *Pseudobranchiomma minima* Nogueira and Knight-Jones, 2002, *Bispira paraporifera* Tovar-Hernández & Salazar-Vallejo, 2006,

B. melanostigma (Schmarda,1861), *Pseudopotamilla intermedia* Moore, 1905, or *Pseudopotamilla fitzhughi* Tovar-Hernández & Salazar-Vallejo, 2006 (Gravier 1906, Nishi 1998, Nogueira and Amaral 2000, Nogueira and Knight-Jones 2002, Capa and López 2004, Tovar-Hernández and Salazar-Vallejo 2006), but the list is probably much longer. In many cases, lack of ecological data on the described species hides the boring habitat of the worm, while in others it is not clear whether the worms were embedded in the hard carbonate substrates or just associated with them.

Scleractinian corals seem to constitute the preferred habitat of the genus *Notaulax*. From the 20 described species of *Notaulax* valid according to Perkins (1984), besides *N. yamasui* sp. n., six are known to bore into coral masses (*N. nudicollis* (Krøyer, 1856); *N. occidentalis* (Baird, 1865); *N. marenzelleri* (Gravier, 1906); *N. pigmentata* (Gravier, 1906); *N. midoculi* (Hoagland, 1919); and *N. bahamensis* Perkins, 1984), and one was found associated with a fossil reef (*N. longithoracalis* (Hartmann-Schröder, 1980)) (Gravier 1906, Perkins 1984, Capa and López 2004, Tovar-Hernández and Salazar-Vallejo 2006). Additionally, Capa and Murray (2015) reported *Notaulax* spp. 1, 2 and 3 from the coral reef of Lizard Island, Great Barrier Reef, Australia. The remainder of the species have been described with no information on the substrates where they were collected, but one indeterminable species (*Notaulax* sp., in Fitzhugh 2002) was found in muddy sand.

Giangrande and Licciano (2004: fig. 4g) reported species richness of the genus *Notaulax* along global latitudinal belts. It is clear that *Notaulax*, being absent from the polar regions, has a preferentially tropical distribution, with the most records occurring between 30°N and S, and a clear domain in the northern hemisphere. This asymmetrical distribution between the hemispheres is probably simply due to a 'concentration effect', a consequence of the higher number of specialists working in the northern hemisphere, where some of the most studied marine faunas of the world are also located (Giangrande and Licciano 2004).

The latitudinal distribution of *Notaulax* fits almost perfectly the global carbonate production, especially as aragonite (Buddemeier 1997: fig. 1; Wood 2001: fig. 1), and by extension, the location of the scleractinian coral reefs (composed mainly by aragonite), also up to about 30°N and S, beyond which coral reefs are usually absent. *Notaulax* species seem to be typically borers, mainly in corals, but also in other carbonate (apparently mainly in aragonite) substrates. Besides the above cited species, references to *Notaulax* specimens as coral borers are frequent in the literature on coral reef polychaetes, especially as unidentified *Hypsicomus* species (e.g., Hartman 1954, Marsden 1960, Peyrot-Clausade et al. 1992, Nishi 1997, Hutchings and Peyrot-Clausade 2002), as *H. elegans* (see Gibbs 1969), *H. phaeotaenia* (see Hutchings et al. 1992), or as *Notaulax* sp. (Nishi and Nishihira 1999, Capa and Murray 2015).

Acknowledgements

We are grateful to late Professor Emeritus Terufumi Yamasu, University of the Ryukyus, for his support during the study of Okinawan polychaetes. We would like to thank

Dr. María Ana Tovar-Hernández and an anonymous reviewer for their criticism and suggestions of useful references that significantly improved the contents and the format of our paper.

References

Baird W (1865) On new tubicolous annelids, in the collection of the British Museum. Part 2. Journal of the Linnean Society of London, Zoology 8(31-32): 157–160. https://doi.org/10.1111/j.1096-3642.1865.tb02433.x

Bok MJ, Nilsson D-E (2016) Fan worm eyes. Current Biology 26(20): R907-R908. https://doi.org/10.1016/j.cub.2016.06.032

Bok MJ, Capa M, Nilsson D-E (2016) Here, there and everywhere: the radiolar eyes of fan worms (Annelida, Sabellidae). Integrative and Comparative Biology 56(5): 784–795. https://doi.org/10.1093/icb/icw089

Bruguière LG (1789) Encyclopedie méthodique. Histoire naturelle des Vers. Paris: Panckouche 1: 1–344. https://doi.org/10.5962/bhl.title.8638

Buddemeier RW (1997) Making light work of adaptation. Nature 388: 229–230. https://doi.org/10.1038/40755

Bush KJ (1905) Tubicolous annelids of the tribes Sabellides and Serpulides from the Pacific Ocean. Harriman Alaska Expedition 12: 169–346. https://doi.org/10.5962/bhl.title.16297

Capa M (2008) The genera *Bispira* Krøyer, 1856 and *Stylomma* Knight-Jones, 1997 (Polychaeta, Sabellidae): systematic revision, relationships with close related taxa and new species from Australia. Hydrobiologia 596(1): 301–327. https://doi.org/10.1007/s10750-007-9105-2

Capa M, Murray A (2015) A taxonomic guide to the fanworms (Sabellidae, Annelida) of Lizard Island, Great Barrier Reef, Australia, including new species and new records. Zootaxa 4019: 98–167. https://doi.org/10.11646/zootaxa.4019.1.8

Capa E, López E (2004) Sabellidae (Annelida: Polychaeta) living in blocks of dead coral in the Coiba National Park, Panama. Journal of the Marine Biological Association of the United Kingdom 84(1): 63–72. https://doi.org/10.1017/S0025315404008926h

Chughtai I, Knight-Jones EW (1988) Burrowing into limestone by sabellid polychaetes. Zoologica Scripta 17(3): 231–238. https://doi.org/10.1111/j.1463-6409.1988.tb00098.x

Claparède E (1870) Les annélides chétopodes du Golfe de Naples. Supplément. Mémoires de la Société de Physique et dHistoire Naturelle de Genève, 20(2): 365–542. https://doi.org/10.5962/bhl.title.105358

Elias RJ (1986) Symbiotic relationships between worms and solitary rugose corals in the Late Ordovician. Paleobiology 12(1): 32–45. https://doi.org/10.1017/S0094837300002967

Fitzhugh K (1989) A systematic revision of the Sabellidae-Caobangiidae-Sabellongidae complex (Annelida: Polychaeta). Bulletin of the American Museum of Natural History 192: 1–104. http://digitallibrary.amnh.org/handle/2246/881

Fitzhugh K (2002) Fan worm polychaetes (Sabellidae: Sabellinae) collected during the Thai-Danish Bioshelf Project. Phuket Marine Biological Center Special Publication 24: 353–424.

Fitzhugh K (2003) A new species of *Megalomma* Johansson, 1927 (Polychaeta: Sabellidae: Sabellinae) from Taiwan, with comments on sabellid dorsal lip classification. Zoological Studies 42(1): 106–134.

Fitzhugh K, Rouse G (1999) A remarkable new genus and species of fan worm (Polychaeta: Sabellidae: Sabellinae) associated with marine gastropods. Invertebrate Biology 118(4): 357–390. https://doi.org/10.2307/3227007

Gardiner JS (1902) The Maldive and Laccadive groups, with notes on other coral formations in the Indian Ocean (continued). The Fauna and Geography of the Maldive and Laccadive Archipelagoes 1(3): 313–346. https://doi.org/10.5962/bhl.title.10215

Giangrande A, Licciano M (2004) Factors influencing latitudinal pattern of biodiversity: an example using Sabellidae (Annelida, Polychaeta). Biodiversity and Conservation 13(9): 1633–1646. https://doi.org/10.1023/B:BIOC.0000029327.63397.6b

Gibbs PE (1969) Aspects of polychaete ecology with particular reference to commensalism. Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences 255: 443–458. https://doi.org/10.1098/rstb.1969.0020

Gravier C (1906) Sur les annélides polychètes de la Mer Rouge (Sabellides). Bulletin du Muséum d'Histoire Naturelle Paris 12(1): 33–43.

Grube AE (1861) Ein Ausflug nach Triest und dem Quarnero. Beiträge zur Kenntniss der Thierwelt dieses Gebietes. Berlin, Nicolaische Verlagsbuchhandlung, 175 pp. https://doi.org/10.5962/bhl.title.7354

Grube AE (1863) Beschreibung neuer oder wenig bekannter Anneliden. Sechster Beitrag. Archive für Naturgeschichte, Berlin 29: 37–69. https://doi.org/10.5962/bhl.part.9306

Grube AE (1868) Beschreibungen einiger von Georg Ritter von Frauenfeld gesammelter Anneliden und Gephyreen des rothen Meeres. Verhandlungen der Kaiserlich-Königlichen Zoologisch-Botanischen Gesellschaft in Wien 18: 629–650.

Grube AE (1870) Bemerkungen über Anneliden des Pariser Museums. Archiv für Naturgeschichte, Berlin 36: 281–352. https://doi.org/10.5962/bhl.part.25781

Grube AE (1874) Über seine im verflossenen August und September ausgeführte Reise nach der Küste von Dalmatien. Jahresbericht der Schlesischen Gesellschaft für Vaterländische Cultur, Breslau 51: 52–56.

Grube AE (1878) Annulata Semperiana. Beiträge zur Kenntniss der Annelidenfauna der Philippinen nach den von Herrn Prof. Semper mitgebrachten Sammlungen. Mémoires de l'Académie impériale des sciences de St. Pétersbourg VII Série 25: ix, 1-300, pls. 1–14. https://doi.org/10.5962/bhl.title.85345

Hartman O (1954) Marine annelids from the Northern Marshall Islands. Geological Survey Professional Papers 260-Q, United States Government Printing Office, Washington, 619–644. https://pubs.er.usgs.gov/publication/pp260Q

Hartmann-Schröder G (1980) Teil 4. Die Polychaeten der tropischen Nordwestküste Australiens (zwischen Port Samson im Norden und Exmouth im Süden). In: Hartmann-Schröder G, Hartmann G. Zur Kenntnis des Eulitorals der australischen Küsten unter besonderer Berücksichtigung der Polychaeten und Ostracoden. Mitteilungen des Hamburgischen Zoologischen Museums und Instituts 77: 41–110.

Hoagland RA (1919) Polychaetous annelids from Porto Rico, the Florida Keys, and Bermuda. Bulletin of the American Museum of Natural History 41: 517–591. http://hdl.handle.net/2246/1161

Hutchings PA (1986) Biological destruction of coral reefs - A review. Coral Reefs 4(4): 239–252. https://doi.org/10.1007/BF00298083

Hutchings PA (2008) Role of polychaetes in bioerosion of coral substrates. In: Wisshak M, Tapanila L (Eds) Current Developments in Bioerosion. Erlangen Earth Conference Series, Springer-Verlag, Berlin Heidelberg, 249–264. https://doi.org/10.1007/978-3-540-77598-0_13

Hutchings PA, Murray A (1982) Patterns of recruitment of polychaetes to coral substrates at Lizard Island, Great Barrier Reef - an experimental approach. Australian Journal of Marine and Freshwater Research 33(6): 1029–1037. https://doi.org/10.1071/MF9821029

Hutchings PA, Kiene WE, Cunningham RB, Donnelly C (1992) Spatial and temporal patterns of non-colonial boring organisms (polychaetes, sipunculans and bivalve molluscs) in *Porites* at Lizard Island, Great Barrier Reef. Coral Reefs 11(1): 23–31. https://doi.org/10.1007/BF00291931

Hutchings PA, Peyrot-Clausade M (2002) The distribution and abundance of boring species of polychaetes and sipunculans in coral substrates in French Polynesia. Journal of Experimental Marine Biology and Ecology 269(1): 101–121. https://doi.org/10.1016/S0022-0981(02)00004-7

Imajima M, Hartman O (1964) The polychaetous annelids of Japan. Part II. Allan Hancock Foundation Publications Occasional Paper 26: 239–452. http://digitallibrary.usc.edu/cdm/ref/collection/p15799coll82/id/18494

Johansson K E (1925) Bemerkungen über die Kinberg'schen Arten der Familien Hermellidae und Sabellidae. Arkiv för Zoologi 18A(7): 1–28.

Jones ML (1974) On the Caobangiidae: A new family of the Polychaeta, with a redescription of *Caobangia billeti* Giard. Smithsonian Contributions to Zoology 175: 1–55. https://doi.org/10.5479/si.00810282.175

Knight-Jones P (1983) Contributions to the taxonomy of Sabellidae (Polychaeta). Zoological Journal of the Linnean Society 79(3): 245–295. https://doi.org/10.1111/j.1096-3642.1983.tb01167.x

Knight-Jones P (1997) Two new species of *Megalomma* (Sabellidae) from Sinai and New Zealand with redescriptions of some types and a new genus. Bulletin of Marine Science 60(2): 313–323.

Knight-Jones P, Perkins TH (1998) A revision of *Sabella*, *Bispira*, and *Stylomma* (Polychaeta: Sabellidae). Zoological Journal of the Linnean Society 123(4): 385–467. https://doi.org/10.1111/j.1096-3642.1998.tb01370.x

Krøyer, H (1856) Meddelelser af en Afhandling om Ormelslaegten *Sabella* Linn., isaer med Hensyn til dens nordiske Arter. Oversigt over det Kongelige Danske videnskabernes selskabs forhandlinger 1856: 1–36.

Kupriyanova EK, Rouse GW (2008) Yet another example of paraphyly in Annelida: molecular evidence that Sabellidae contains Serpulidae. Molecular Phylogenetics and Evolution 6(3): 1174–1181. https://doi.org/10.1016/j.ympev.2007.10.025

Kuris AM, Culver CS (1999) An introduced sabellid polychaete pest infesting cultured abalones and its potential spread to other California gastropods. Invertebrate Biology 118(4): 391–403. http://www.jstor.org/stable/3227008

Langerhans P (1880) Die wurmfauna Madeiras. II. Zeitschrift für wissenschaftliche Zoologie 33(1-2): 271–316.

Linnaeus C (1767) Systema Naturae per Regna Tria Naturae, Edito Duodecima Reformata, Tomus I, Pars II. Regnum Animale. Stockholm: Laurentii Salvii, 533–1327 + 1–37. https://doi.org/10.5962/bhl.title.68927

Marsden JR (1960) Polychaetous annelids from the shallow waters around Barbados and other islands of the West Indies, with notes on larval forms. Canadian Journal of Zoology 38(5): 989–1020. https://doi.org/10.1139/z60-104

Moore JP (1905) Five new species of *Pseudopotamilla* from the Pacific coast of North America. Proceedings of the Academy of Natural Sciences of Philadelphia 57: 555–569. http://www.jstor.org/stable/4063036

Moore JP (1923) The polychaetous annelids dredged by the U.S.S. "Albatross" off the coast of southern California in 1904. IV. Spionidae to Sabellariidae. Proceedings of the Academy of Natural Sciences of Philadelphia 75: 179–259. http://www.jstor.org/stable/4063880

Moore JP, Bush KJ (1904) Sabellidae and Serpulidae from Japan, with descriptions of new species of *Spirorbis*. Proceedings of the Academy of Natural Sciences of Philadelphia 56: 157–179. http://www.jstor.org/stable/4062850

Moreno RA, Neill PE, Rozbaczylo N (2006) Native and non-indigenous boring polychaetes in Chile: A threat to native and commercial mollusc species. Revista Chilena de Historia Natural 79(2): 263–278. https://doi.org/10.4067/S0716-078X2006000200012

Nishi E (1997) Ageing infauna from host coral growth bands. Reef Encounter 21: 15–16.

Nishi E (1998) A new species of *Megalomma* (Annelida: Polychaeta: Sabellidae) from Phuket, Thailand. Pacific Science 52(1): 53–60. http://hdl.handle.net/10125/1558.

Nishi E, Nishihira M (1999) Use of annual density banding to estimate longevity of infauna of massive corals. Fisheries Science 65(1): 48–56.

Nogueira JMM, Amaral ACZ (2000) *Amphicorina schlenzae*, a small sabellid (Polychaeta, Sabellidae) associated with a stony coral on the coast of São Paulo State, Brazil. Bulletin of Marine Science 67(1): 617–624.

Nogueira JMM, Knight-Jones P (2002) A new species of *Pseudobranchiomma* Jones (Polychaeta: Sabellidae) found amongst Brazilian coral, with a redescription of *P. punctata* (Treadwell, 1906) from Hawaii. Journal of Natural History 36(14): 1661–1670. https://doi.org/10.1080/00222930110071705

Nogueira JMM, Fitzhugh K, Rossi MCS (2010) A new genus and new species of fan worms (Polychaeta: Sabellidae) from Atlantic and Pacific Oceans – the formal treatment of taxon names as explanatory hypotheses. Zootaxa 2603: 1–52.

Perkins TH (1984) Revision of *Demonax* Kinberg, *Hypsicomus* Grube, and *Notaulax* Tauber, with a review of *Megalomma* Johansson from Florida (Polychaeta: Sabellidae). Proceedings of the Biological Society of Washington 97(2): 285–368.

Peyrot-Clausade M, Hutchings PA, Richard G (1992) Temporal variations of macroborers in massive *Porites lobata* on Moorea, French Polynesia. Coral Reefs 11 (3): 161–166. https://doi.org/10.1007/BF00255471

Quatrefages A (1866) Histoire naturelle des annelés marins et d'eau douce. Annélides et géphyriens. Tome second. Deuxième partie. Librarie Encyclopédique de Roret, Paris, 337–794. https://doi.org/10.5962/bhl.title.122818

Renier SA (1847) Osservazioni postume di Zoologia Adriatica, del Professore Stefano Andrea Renier, membro effettivo dell'Instituto Italiano, pubblicate per cura dell'I. R. Istituto Veneto di Scienze, Lettere er Arti a studio del membro effettivo Prof. G. Meneghini. Giovanni Cecchini Venezia, 122 pp.

Rullier F, Amoureux L (1970) Nouvelle contribution à l'étude de la faune des Annélides Polychètes du Maroc. Bulletin de la Société des Sciences Naturelles et Physiques du Maroc 49(1/2): 109–142.

Schmarda LK (1861) Neue Turbellarien, Rotatorien und Anneliden. Neue wirbellose Thiere beobachtet und gesammelt auf einer Reise un die Erde 1853 bis 1857. 1(2): 1–164. https://doi.org/10.5962/bhl.title.85313

Shaw G (1800) XXI. Descriptions of the *Mus Bursarius* and *Tubularia Magnifica*; from drawings communicated by Major-General Thomas Davies, F.R.S. & L.S. Transactions of the Linnean Society of London 5(1): 227–229. https://doi.org/10.1111/j.1096-3642.1800.tb00593.x

Simon CA, Kaiser H, Britz PJ (2005) The life history responses of the abalone pest, *Terebrasabella heterouncinata*, under natural and aquaculture conditions. Marine Biology 147(1): 135–144. https://doi.org/10.1007/s00227-005-1552-6

Tauber P (1879) Annulata Danica. En kritisk revision af de i Danmark Fundne Annulata, Chaetognatha, Gephyrea, Balanoglossi, Discophoreae, Oligochaeta, Gymnocopa og Polychaeta. Reitzel, Kjøbenhavn, 144 pp.

Tovar-Hernández MA, Salazar-Vallejo SI (2006) Sabellids (Polychaeta: Sabellidae) from the Grand Caribbean. Zoological Studies 45(1): 24–66.

Tovar-Hernández MA, Harris, LH (2010) *Parasabella* Bush, 1905, replacement name for the polychaete genus *Demonax* Kinberg, 1867 (Annelida, Polychaeta, Sabellidae). ZooKeys 60: 13–19. https://doi.org/10.3897/zookeys.60.547

Tovar-Hernández MA, Pineda-Vera A (2007) Taxonomía y estrategias reproductivas del poliqueto sabélido *Bispira brunnea* (Treadwell, 1917) del Caribe mexicano. Ciencia y Mar 2007 11 (33): 3–14.

Warme JE (1975) Boring as trace fossils and the processes of marine bioerosion. In: Frey RW (Ed.) The study of trace fossils. Springer-Verlag, New York, 181–228. https://doi.org/10.1007/978-3-642-65923-2_11

Wiktor K (1980) Type-specimens of Annelida Polychaeta in the Museum of Natural History of the Wrocław University. Annales Zoologici, Warszawa 35(20): 267–283.

Wood R (2001) Biodiversity and the history of reefs. Geological Journal 36(3-4): 251–263. https://doi.org/10.1002/gj.898